ASSIST *recommends...*

LED Life for General Lighting: Definition of Life

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Lighting Research Center

Rensselaer

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Purpose

This document outlines a proposed definition of useful life for light-emitting diode (LED) components and systems used for general lighting applications. The audience for this document is LED component and system manufacturers.

Background

LEDs exhibit very long operational life characteristics, typically 50,000 hours or longer. Like all light sources, LEDs slowly decrease in light output over time. Because they rarely fail, situations can occur where LEDs are emitting less light than intended by the specifier, yet still appear to be operating. LEDs can also undergo gradual shifts in color that result in an unacceptable appearance.

Because of these characteristics, the ASSIST program has developed a set of proposed definitions for the useful life of white LED components and white LED lighting systems.

Components and Systems

For the purpose of this document, an LED component is defined as the individual LED light source. One or many LED components may be assembled with a driver and housing to create an LED lighting system. An LED system is defined as the integration of all necessary components into a working module, such as a light fixture.

Life Definition

The reported life of an LED component or system is to be defined as the operating time (L, in hours) for the component or system to reach two performance criteria:

$L_{70\%}$ (hours): time to 70% lumen maintenance

$L_{50\%}$ (hours): time to 50% lumen maintenance

Within these times, the LED component or system should not exhibit chromaticity shifts greater than those bounded by a four-step MacAdam ellipse.

These times are to be measured under specific conditions as outlined in the accompanying documents, "LED Life for General Lighting — Measurement Method for LED Components" and “LED Life for General Lighting — Measurement Method for LED Systems.”

Rationale

For general lighting applications, 70% lumen maintenance, which corresponds to a 30% reduction from the initial light output of a lighting system, is close to the threshold for detecting gradual reductions in light output. Research shows also that reductions to 70% of initial light output are considered acceptable by the majority of occupants within a space. Thus, this level is unlikely to be problematic for a wide array of lighting applications. Indeed, lumen maintenance values greater than 70% are achieved by most successful general light sources throughout their operating life.

When the appearance and output of a particular lighting application are critical (e.g., wall washing in a corridor where the light sources are seen side by side), useful life based on 80% lumen maintenance should be considered. For other applications where light output is not critical to the performance of a lighting system, such as decorative applications, reductions of 50% might be acceptable. Providing the operating time to reach at least two levels of light output will assist specifiers and manufacturers in predicting useful life based on other lumen maintenance criteria.

About ASSIST

ASSIST was established in 2002 by the Lighting Research Center at Rensselaer Polytechnic Institute to advance the effective use of energy-efficient solid-state lighting and speed its market acceptance. ASSIST's goal is to identify and reduce major technical hurdles and help LED technology gain widespread use in lighting applications that can benefit from this rapidly advancing light source.

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LED Life for General Lighting: Measurement Method for LED Components

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Purpose

This document outlines a method for measuring useful life for light-emitting diode (LED) components used in general lighting systems. The intent of this document is to encourage common methods of testing and data presentation. The target audience is LED component manufacturers.

Scope

An LED component is defined as the individual LED light source. One or many LED components may be assembled with a driver and housing to create an LED lighting system.

The measurement method defined here is to be used to determine the operational life in hours for an LED component to reach $L_{70\%}$ and $L_{50\%}$. These data are to be presented by LED component manufacturers and used by LED system manufacturers.

Method

For the purpose of measuring useful life, the component should first be operated for a 1,000-hour seasoning period at the rated current and voltage. Then the component should be monitored while operating at rated current for at least an additional 5,000 hours (for a total of 6,000 hours) at three different temperatures (T_s) measured directly on the component. T_s is the temperature of the thermocouple attachment point on the LED. This point is usually the solder joint or the closest measurable location to the LED junction. Manufacturers should diagram the thermocouple attachment point. For high-power LED components (those operated above 100 mA), the recommended T_s temperatures are 45°C, 65°C, and 85°C. For low-power LEDs (those operated below 100 mA), the recommended T_s temperatures are 35°C, 45°C, and 55°C.

It may be assumed that the spatial and spectral distributions from the component do not change significantly over its useful life. A broadband detector measuring radiant flux may be used as a surrogate for luminous output rather than requiring expensive $V(\lambda)$ correction in measurement equipment, since it is the relative output change that is of interest.

If $L_{70\%}$ and $L_{50\%}$ are not reached within 6,000 hours, a functional fit (provided by the LED or system manufacturer[1]) to the data between 1,000 and 6,000 hours (i.e., excluding the first 1,000 hours) can be used to extrapolate to 70% and 50% lumen maintenance.

For the purpose of this measurement method, lumen maintenance is defined as the light output as a percentage of the component's output after the 1,000-hour seasoning period. The 1,000 hour data value is normalized to 100%. The reason for omitting the initial 1,000 hours is because for most LEDs, the light output increases during this period. After this period, the light output begins to decrease.

[1] No single type of functional fit (for example, an exponential fit) is applicable to all LED packages because package configuration variations can result in different degradation mechanisms, which affect the shape and rate of light output depreciation.

The time it takes for an LED to reach this maximum depends on the device and the temperature.

As product performance improves in the future, the initial seasoning period may get longer, and a measurement period greater than 6,000 hours may be necessary to develop reasonable predictions of light output.

Additional Data

To aid the successful integration of LEDs into a system, system manufacturers require additional measurements and documentation. The following data pertaining to the conditions of measurement should also be reported:

- Number of product samples tested
- Heat sink description (size, shape, materials, etc.)
- Ambient temperatures corresponding to the T_s temperatures
- θ_r: thermal resistance coefficients of the LED junction to the location where the thermocouple is mounted in °C/W, corresponding to the three test temperatures
- V: voltage across the leads, reported at the three test temperatures
- I: current through the device, reported at the three test temperatures

These data permit estimation of the junction temperature (T_j) that corresponds to the life data.

$$T_j = T_s + V \cdot I \cdot \theta_r$$

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LED Life for General Lighting: Measurement Method for LED Systems

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Purpose

This document outlines a method for measuring useful life for light-emitting diode (LED) systems used for general lighting applications. The intent of this document is to encourage common methods of testing and data presentation. The target audience is LED system manufacturers.

Scope

An LED system is defined as the integration of all necessary components into a working module, such as a light fixture. An LED system may contain one or more LED components along with a driver and housing.

The measurement method defined here is to be used to determine the operational life in hours for an LED system to reach $L_{70\%}$ and $L_{50\%}$. These data are to be presented by LED system manufacturers and used by lighting specifiers.

Method

For the purpose of measuring useful life, the system should first be operated for a 1,000-hour seasoning period at the rated current and voltage. Then, the system should be monitored while operating at rated current for at least an additional 5,000 hours (for a total of 6,000 hours) in a ventilated environment at an ambient temperature of 25°C. For systems intended to operate in environments where the heat buildup causes the LED junction temperature to increase, the LED system should be tested at temperatures (T_s) corresponding to those environments for which they are rated. T_s, measured directly on the LED component, is the temperature of the thermocouple attachment point on the LED or the LED board. This point is usually the solder joint or the closest measurable location to the LED junction. T_s must be first determined by operating the system under conditions similar to the one or more environments where it would be used. For example, indoor directional lighting systems typically operate in three different environments, namely open air, semi-ventilated, and enclosed.[1]

It may be assumed that the spatial and spectral distributions from the system do not change significantly over its useful life. A broadband detector measuring radiant flux may be used as a surrogate for luminous output rather than requiring expensive $V(\lambda)$ correction in measurement equipment, since it is the relative output change that is of interest.

If $L_{70\%}$ and $L_{50\%}$ are not reached within 6,000 hours, a functional fit (provided by the LED or system manufacturer[2]) to the data between 1,000 and 6,000 hours (i.e., excluding the first 1,000 hours) can be used to extrapolate to 70% and 50% lumen maintenance. For the purpose of this measurement method, lumen maintenance is defined as the light output as a percentage of its output after the initial 1,000-hours. The 1,000 hour data value is normalized to 100%. The reason

[1] *ASSIST recommends… Recommendations for Testing and Evaluating Luminaires Used in Directional Lighting*. Vol. 3, Issue 3. Internet: http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/directional.asp

[2] No single type of functional fit (for example, an exponential fit) is applicable to all LED packages because package configuration variations can result in different degradation mechanisms, which affect the shape and rate of light output depreciation.

for omitting the initial 1,000 hours is because for most LEDs, the light output increases during this period. After this period, the light output begins to decrease. The time it takes for an LED to reach this maximum depends on the device and the temperature.

As product performance improves in the future, the initial seasoning period may get longer, and a measurement period greater than 6,000 hours may be necessary to develop reasonable predictions of light output.

Additional Data

In addition to providing $L_{70\%}$ and $L_{50\%}$ life data, LED system manufacturers should also provide the number of product samples tested.

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LED Life for General Lighting: Sample Data Sheet for High-power LEDs

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Data Sheet – High-power LED Life

This document outlines the life data and testing information that component manufacturers of high-power LEDs should provide. This data is to be measured under specific conditions as outlined in the accompanying document, "LED Life for General Lighting — Measurement Method for LED Components," Vol. 1, Issue 2.

Product Information

Product Name ____

Product Number ____

Test Date(s) ____

Testing Procedure

[Briefly outline the procedure and equipment used to derive life data presented in this document. Include a diagram showing the thermocouple attachment point.]

Life Data

T_s	45°C	65°C	85°C
$L_{70\%}$ (hours)			
$L_{50\%}$ (hours)			

* T_s is the temperature of the point on the LED where the thermocouple is attached. This point is usually the solder joint or closest measurable location to the LED junction.

45°C Life Graph	65°C Life Graph	85°C Life Graph
[Insert life graph here]	[Insert life graph here]	[Insert life graph here]

Additional Data

Number of product samples tested ______________________________

Heat sink description (size, shape, materials, etc.)______________________________

Ambient temperatures corresponding to T_s temperatures:

@T_s 45°C ___________ @T_s 65°C ___________ @T_s 85°C ___________

Thermal resistance coefficients of the LED junction to the T_s measurement point, in °C/W (θ_r):

@T_s 45°C ___________ @T_s 65°C ___________ @T_s 85°C ___________

Voltage across the leads (V):

@T_s 45°C ___________ @T_s 65°C ___________ @T_s 85°C ___________

Current through the device (I):

@T_s 45°C ___________ @T_s 65°C ___________ @T_s 85°C ___________

Junction temperature ($T_j = T_s + V \cdot I \cdot \theta_r$):

@T_s 45°C ____________ @T_s 65°C ____________ @T_s 85°C ____________

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LED Life for General Lighting: Sample Data Sheet for Low-power LEDs

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Data Sheet – Low-power LED Life

This document outlines the life data and testing information that component manufacturers of low-power LEDs should provide. This data is to be measured under specific conditions as outlined in the accompanying document, "LED Life for General Lighting — Measurement Method for LED Components," Vol. 1, Issue 2.

Product Information

Product Name ____

Product Number ____

Test Date(s) ____

Testing Procedure

[Briefly outline the procedure and equipment used to derive life data presented in this document. Include a diagram showing the thermocouple attachment point.]

Life Data

T_s	35°C	45°C	55°C
$L_{70\%}$ (hours)			
$L_{50\%}$ (hours)			

* T_s is the temperature of the point on the LED where the thermocouple is attached. This point is usually the solder joint or closest measurable location to the LED junction.

35°C Life Graph

[Insert life graph here]

45°C Life Graph

[Insert life graph here]

55°C Life Graph

[Insert life graph here]

Additional Data

Number of product samples tested ______________________________

Heat sink description (size, shape, materials, etc.)______________________

Ambient temperatures corresponding to T_s temperatures:

@T_s 35°C ___________ @T_s 45°C ___________ @T_s 55°C ___________

Thermal resistance coefficients of the LED junction to the T_s measurement point, in °C/W (θ_r):

@T_s 35°C ___________ @T_s 45°C ___________ @T_s 55°C ___________

Voltage across the leads (V):

@T_s 35°C ___________ @T_s 45°C ___________ @T_s 55°C ___________

Current through the device (I):

@T_s 35°C ___________ @T_s 45°C ___________ @T_s 55°C ___________

Junction temperature ($T_j = T_s + V \cdot I \cdot \theta_r$):

@T_s 35°C ____________ @T_s 45°C ____________ @T_s 55°C ____________

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LED Life for General Lighting: Sample Data Sheet for LED Systems

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Data Sheet – LED System Life

This document outlines the life data and testing information that manufacturers of LED systems should provide. This data is to be measured under specific conditions as outlined in the accompanying document, "LED Life for General Lighting — Measurement Method for LED Systems," Vol. 1, Issue 3.

Product Information

Product Name ____

Product Number ____

Test Date(s) ____

Testing Procedure

[Briefly outline the procedure and equipment used to derive life data presented in this document. Include a diagram showing the thermocouple attachment point.]

Life Data

Operating Temperature	T_s at 25°C ambient temperature	T_{s1} as determined for additional environment	T_{s2} as determined for additional environment
$L_{70\%}$ (hours)			
$L_{50\%}$ (hours)			

25°C Life Graph	T_{s1} Life Graph	T_{s2} Life Graph
[Insert life graph here]	[Insert life graph here]	[Insert life graph here]

Additional Data

Number of product samples tested____

About ASSIST

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ASSIST *recommends...*

LED Life for General Lighting: Recommendations for the Definition and Specification of Useful Life for Light-emitting Diode Light Sources

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Introduction

This document outlines a recommendation for the definition and specification of useful life for light sources and lighting systems using light-emitting diodes (LEDs). It was developed by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in collaboration with members of the Alliance for Solid-State Illumination Systems and Technologies (ASSIST).

Background

Traditionally, the definition of life for light sources is based on the median operating time that can be expected under specified conditions (Rea, 2000). For example, fluorescent lamps are operated on a 3-hr-on, 20-min-off cycle at a temperature of 25°C. After a certain amount of time, the light source is expected to fail and no longer function. Based on this definition, the life of LED sources would often be in excess of 100,000 hr because the solid-state components have no obvious failure mechanism. However, it has been shown that nearly all light sources, including LEDs, experience both gradual reductions in light output and gradual shifts in color appearance.

The term *lumen maintenance* refers to the output of a light source at a given instance relative to its initial light output when brand new. Narendran et al. (2000, 2001) demonstrated that some LED sources (e.g., 5-mm packages designed for indicator applications), when operated under rated conditions, reach less than 50% lumen maintenance well before 10,000 hr—much shorter than the 100,000+ hr life until failure. More recent LED configurations designed to provide illumination maintain lumen output for much longer periods of time, with approximately 80% lumen maintenance at 20,000 hr.

Color shifts as a function of time have also been demonstrated in LEDs. Narendran et al. (2001) demonstrated shifts in chromaticity of individual 5-mm indicator packages approaching the size of a four-step MacAdam ellipse (thought to be detectable by well over 99% of the population; see MacAdam, 1942) after only 1100 hr of operation. Similar shifts were observed for individual illumination-grade devices after 2000 hr of operation, demonstrating improvements in control of color shifts (Narendran et al., 2003).

Since a light source that produces only a fraction of its initial light output, or that shifts considerably in color appearance over time, is arguably not a very useful source, a definition of useful life that is an alternative to the conventional time until failure is proposed. The alternative definition takes into account the longevity of LEDs as well as their lumen maintenance and color shift characteristics. For lumen maintenance issues, two levels of useful life are proposed based on the variety of applications for which LEDs might be used. For color shifts, it is proposed that the useful life definition be invoked only when color appearance is important for the intended application.

Proposed Definition

It is proposed that the useful life of an LED light source (e.g., a bare LED component) or an LED lighting system with regard to lumen depreciation be defined in two ways: one is the length of time that source or system takes, when operated at a specified temperature, to reach 70% of its initial light output ($L_{70\%}$);

and the other, the length of time to reach 50% ($L_{50\%}$) of its initial light output under the same operating conditions. With regard to color shift, it is proposed that throughout the useful life, the chromaticity coordinates of the source or system should not fall outside a four-step MacAdam ellipse (L_{4M}) containing the initial chromaticity coordinates. It should be noted that the useful life of an LED light source is unlikely to remain the same when it is integrated into a lighting system. End users of a particular LED lighting system should seek the system's life value.

Rationale

Comparison Among Technologies

A comparison of lumen maintenance characteristics of light sources (Rea, 2000; Bullough, 2003) demonstrates that most conventional light sources (e.g., filament lamps, fluorescent lamps and high pressure sodium lamps) exhibit greater than 70% lumen maintenance by the time they have operated for their rated life, or 20,000 hr, whichever comes first (Figure 1). Indeed, much of the trade literature in the lighting industry (e.g., Anonymous, 1998, 2002; Knisley, 2001; Simpson, 2002) points to lumen maintenance values in excess of 80% or 90% as being desirable characteristics of general lighting sources.

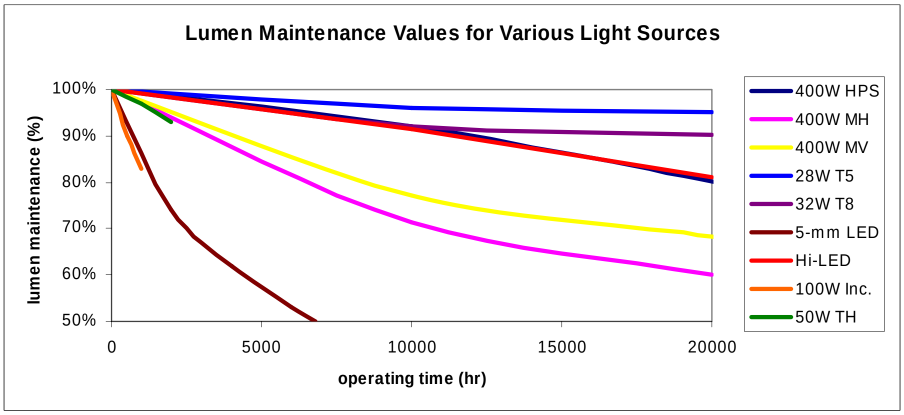

Figure 1. Lumen maintenance curves for different light sources out to 20,000 hours (Rea, 2000; Bullough, 2003).

Important exceptions to this analysis are mercury vapor and metal halide lamps, which regularly reach less than 70% of initial light output during their rated lifetime. Since mercury vapor lamps have relative low luminous efficacy and color rendering indices compared to metal halide lamps, these sources are not considered further in this document. Regarding metal halide lamps, their relatively low lumen maintenance attributes are recognized in the literature (Brates and Hrubowchak, 1999; Fetters, 1999), and lumen maintenance values of 80% to 85% are being cited as appropriate short-term target values for these lamps in the future.

Relatively few data are available on color shifts with different light sources over time, with the exceptions of LEDs, described above (Narendran et al., 2001, 2003), and metal halide lamps (Carleton et al., 1997; Krasko et al., 1998). Carleton et al. (1997) showed that metal halide lamps with quartz arc tubes experienced shifts in chromaticity greatly exceeding a four-step MacAdam ellipse after 5000 hr of operation, and lamps with ceramic arc tubes remaining well within a four-step MacAdam ellipse in terms of chromaticity. Krasko et al. (1998) did not report chromaticity shifts but rather shifts in correlated color temperature, demonstrating shifts of 200-300 K by 4000 hr, which approximates in magnitude the color shift described by a four-step MacAdam ellipse.

Human Response

The Illuminating Engineering Society of North America (IESNA) (Rea, 2000) states that a difference in illuminance of about one-third (~33%) from a given value constitutes a dramatic difference. If, as is often the case, the goal of a general lighting installation is not to look dramatically different from the norm, a difference of 30% in light level (e.g., no less than 70% of the initial level) would provide a reasonable basis for avoiding dramatically noticeable differences.

Changes in light output caused by lumen maintenance reductions are very slow and gradual. While there is extensive research on the visual response to very rapid fluctuations in light level (e.g., flicker), the lighting and vision science literature is much sparser regarding the response to slow changes in light level. With recent developments in the electric utility industry in North America and Europe, however, the concept of using reductions in light levels through dimming during periods of peak electricity use has become a potentially attractive option for avoiding blackouts. In that context, several studies of the responses of occupants to relatively slow (over several seconds or minutes) reductions in light output are of interest and could also provide insight as to the detectability of light level reductions over the life of a lighting installation:

- Knau (2000) measured the ability of observers to detect differences in light level viewed as a perfectly uniform, full field of view. Knau (2000) found that when the initial luminance was 10 or 100 cd/m^2 and was reduced slowly, the change in level was detected after a reduction of about 20% to 40%.
- Kryszczuk and Boyce (2002) measured the time taken by observers to notice illuminance reductions in a simulated office environment. Regardless of the initial illuminance (about 500 or 1000 lx), the speed of reduction (from about 4 to 300 lx/s), or whether the occupant was given a mental distraction task, the difference was typically noticed when the illuminance reduction was between 17% and 22%.
- Shikakura et al. (2003) found that observers could notice a 10% immediate reduction in illuminance (from 450 or 700 lx) if they were focused only on trying to notice that difference. When observers were given typical office-type tasks, the noticeable difference increased to 20%. Increasing the length of time for the decrease from 2 to 8 s tended to increase the noticeable difference only when an office-type task was simultaneously performed.
- Akashi and Neches (2004) also measured observers' ability to detect slow (over a period of 10 s) reductions in illuminance (from 500 lx) and found that reductions of about 15% to 30% were needed before they could be detected by a majority of subjects. In addition, a majority of subjects found a 30% reduction acceptable (for the purpose of reducing peak load), even if they could detect it.

In general, these studies suggest that reductions in light level to about 70% to 80% of its initial value are the likely minimum change that would not be detected reliably by observers. Likely, the characteristics of the specific luminous environment and the nature of the tasks being performed impact the magnitude of the detectable reduction, given differences among the studies. The evidence from Akashi and Neches (2004) indicates that even when reductions in light level are detected, they can still be considered acceptable.

Regarding color shifts, Narendran et al. (2000) reported that differences in chromaticity approximating a four-step MacAdam ellipse appeared to be a reasonable tolerance for perceptions of color differences in a display containing a variety of colored objects. Since color shifts over time would not be seen in a side-by-side but rather in sequential mode, such a color shift magnitude appears to be a reasonable one for minimizing detection of such shifts.

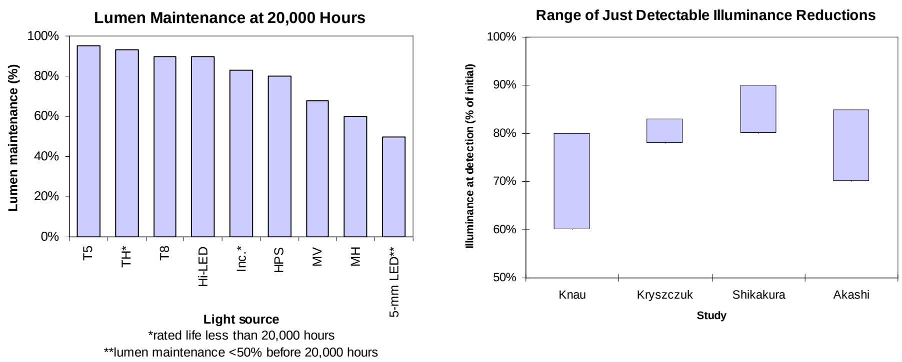

Figure 2. (a; left) Lumen maintenance values for light sources at 20,000 hours or end of life. (b; right) Summary of detectable illuminance reductions from several studies.

Conclusions

Based on the performance characteristics of conventional lighting technologies regarding lumen maintenance (summarized in Figure 2a), as well as the responses of people to the lighted environment (Figure 2b), a lumen maintenance value of 70% is justified as the basis for determining the end of useful life for an LED light source in general lighting applications ($L_{70\%}$). Of course, this recommendation is applicable only to general illumination applications such as those found in commercial interior lighting. For some applications where uniform appearance of the lighted environment is one of the primary criteria (e.g., wall washing in a corridor), a more stringent requirement, such as 80% lumen maintenance, could be necessary. Yet other applications, such as decorative lighting, could well have much less stringent requirements, provided by a 50% criterion for light output ($L_{50\%}$). Applications such as emergency lighting, for example, are subject to specific regulations and requirements and are considered outside the scope of this definition.

When color appearance of lighting is an important consideration, a further useful life value is proposed based on the tolerances of human perception for detecting color shifts. Using the time for a light source to shift in chromaticity outside a four-step MacAdam ellipse containing the source's initial chromaticity coordinates (L_{4M}) is therefore proposed as a basis for useful life when color appearance consistency over time is important.

References

Akashi Y, Neches J. 2004. Detectability and acceptability of illuminance reduction for load shedding. *J Illum Eng Soc* 33(1): 3-13.

Anonymous. 1998. Demand and regs lift lamp demand slightly. *Purchasing* 124(4): 96-98.

Anonymous. 2002. *Buildings* magazine: Editors' choice top 100 products 2002. *Buildings* 96(12): 25-56.

Brates N, Hrubowchak DM. 1999. Investigations of sodium-scandium and sodium-rare earth chemistries for 4000K, high CRI metal halide lamps. *J Illum Eng Soc* 28(1): 103-116.

Bullough JD. 2003. *Lighting Answers: Light Emitting Diode Lighting Systems*. Troy: National Lighting Product Information Program, Lighting Research Center, Rensselaer Polytechnic Institute.

Carleton S, Seinen PA, Stoffels J. 1997. Metal halide lamps with ceramic envelopes: A breakthrough in color control. *J Illum Eng Soc* 26(1): 139-145.

Fetters JL. 1999. Lighting efficiency: Making it happen, part I. *Elec Const Maint* 98(4): 40-42.

Knau H. 2000. Thresholds for detecting slowly changing *Ganzfeld* luminances. *J Opt Soc Am A* 17(8): 1382-1387.

Knisley J. 2001. Standard knowledge. *Elect Const Maint* 100(4): 84-86.

Krasko Z, Brates N, Nortrup E. 1998. Optimization of metal halide lamp design for better color rendering and color control. *J Illum Eng Soc* 27(2): 152-159.

Kryszczuk K, Boyce PR. 2002. Detection of slow light level reduction. *J Illum Eng Soc* 31(2): 3-10.

MacAdam DL. 1942. Visual sensitivities to color differences in daylight. *J Opt Soc Am* 32(5): 247-274.

Narendran N, Vasconez S, Boyce PR, Eklund N. 2000. Just-perceivable color differences between similar light sources in display lighting applications. *J Illum Eng Soc* 29(2): 68-77.

Narendran N, Maliyagoda N, Bierman A, Pysar RM, Overington M. 2000. Characterizing white LEDs for general illumination applications *Proc SPIE Int Soc Opt Eng 3938*, pp. 240.

Narendran N, Bullough JD, Maliyagoda N, Bierman A. 2001. What is useful life for white light LEDs? *J Illum Eng Soc* 30(1): 57-67.

Narendran N, Deng L, Pysar RM, Gu Y, Yu H. 2003. Performance characteristics of high-power light emitting diodes. *Proc SPIE Int Soc Opt Eng 5187*.

Rea MS (ed.). 2000. *IESNA Lighting Handbook: Reference and Application*, 9th ed. New York: Illuminating Engineering Society of North America.

Shikakura T, Morikawa H, Nakamura Y. 2003. Perception of lighting fluctuation in office lighting environment. *J Light Vis Env* 27(2): 75-82.

Simpson T. 2002. Fluorescent and HID duke it out. *Plant Eng* 56(10): 60-62.

About ASSIST

ASSIST was established in 2002 by the Lighting Research Center at Rensselaer Polytechnic Institute to advance the effective use of energy-efficient solid-state lighting and speed its market acceptance. ASSIST's goal is to identify and reduce major technical hurdles and help LED technology gain widespread use in lighting applications that can benefit from this rapidly advancing light source.